Nonlinear pulse combining and compression in multi-core fibers with hexagonal lattice

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Abstract: We demonstrate an effective combining and compression using multi-core fibers with a hexagonal lattice numerically. We investigate the optimal operational conditions for maximal combining and compression and analyze a positive chirp influence.
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1. Introduction

Multi-core optical fibers (MCF) have many applications in various areas of photonics. Especially, they offer the great possibility of spatial-division multiplexing (SDM) for high capacity optical communications. Recently we have demonstrated another application of multi-core fibers – the possibility of nonlinear pulse combining and compression [1]. In a MCF with 7 cores arranged in a circle, we have demonstrated numerically the combining of 82.8% of the energy into one core with simultaneous pulse compression over 6.6x. In a 20-core ring MCF the values 72.7% and 17.4x, respectively, were obtained by simulation.

In this paper, we consider MCFs only with hexagonal lattice and present the results of pulse combining and compression optimization for this cores placement (see Fig. 1a). A hexagonal structure of cores demonstrates improvements in combining performance as compared with a ring structure. The required length of the hexagonal MCF for obtaining compressed pulse is much shorter. The increase in the number of neighbors enhances nonlinear effects and can make the compression and combining more robust and efficient. We performed massive numerical simulations to determine the conditions of most efficient coherent combining of chirped and non-chirped pulses injected into considered MCF. Calculations showed a possibility of combining up to 96.5% of total energy into one core.

2. Theory and simulations

The dynamic of the field envelope $U_{n,m}$ in core (n,m) of a hexagonal MCF can be described in dimensionless variables by the discrete-continuous nonlinear Schrodinger equation (NLSE) [2]:

$$i\frac{\partial U_{n,m}}{\partial z}+\frac{\partial^2 U_{n,m}}{\partial t^2}+(\underline{CU})_{n,m}+|U_{n,m}|^2U_{n,m}=0, \tag{1}$$

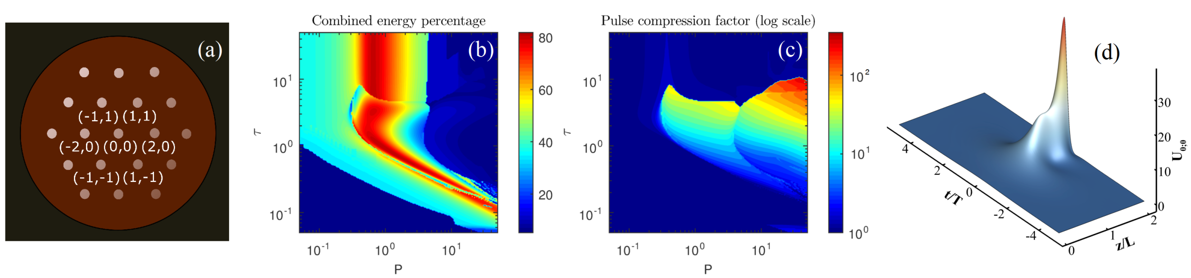

Fig. 1. Scheme of considered hexagonal 19-core MCF (a). The dependence of the pulse compression factor (b) and the percentage of total energy combined in the central core at the first local maximum of the peak power of input pulse (c) on the parameters P and τ of input Gaussian pulses for the hexagonal 19-core MCF. Dynamic of the field in the center core for the best combining case ($P=0.36,\ \tau=1.69$) with 80.9% of energy combining.

where $(\underline{CU})_{n,m} = U_{n-1,m-1} + U_{n+1,m-1} + U_{n-2,m} + U_{n+2,m} + U_{n-1,m+1} + U_{n+1,m+1} - 6U_{n,m}$. We simulated the dynamic of initially chirped Gaussian pulses $U_{n,m}(t) = \exp\left[-(1+iC)t^2/(2\tau^2)\right]$, where $C \geq 0$, injected in all cores of a 19-core hexagonal MCF to define values of amplitudes P and widths τ of the initial pulses which provide the most efficient pulse combining and pulse compression. We tracked the first local maximum of the peak power of the pulse propagating in the central core $(0,0)$ of the MCF to define the compression point and characteristics of the compressed pulse.

First, consider the case of non-chirped initial Gaussian pulses. The dependence of the pulse compression factor (ratio of the initial full width at half maximum to the final one) on the parameters P and τ for a hexagonal MCF is presented in Fig. 1b. The blue area denotes pairs of parameters P, τ, for which there is no pulse compression or the initial pulses with this parameters are compressed after the length along fiber where the first local maximum of peak power was obtained. The maximum value of the pulse temporal compression is about 250x. The percentage of total energy $E = \sum_{n,m} \int_{-\infty}^{\infty} |U_{n,m}(z,t)|^2 dt$ combined at the first maximum of pulse peak power in the core $(0,0)$ is shown in Fig. 1c. There is a wide area of parameters P, τ with more than 70% of the combined energy at the central core. Therefore, the hexagonal 19-core MCF has an advantage of being useful as a base of the optical pulse compressor device. It is interesting that the effective compression and effective combining cannot be reachable simultaneously. Note, that the compression keeps the beam shape smooth, suitable for further propagation and utilization (see Fig. 1d, where the best combining case ($P = 0.36,\ \tau = 1.69$) is presented with combining 80.9% of total energy E and reduction of pulse temporal duration at 7.3 times).

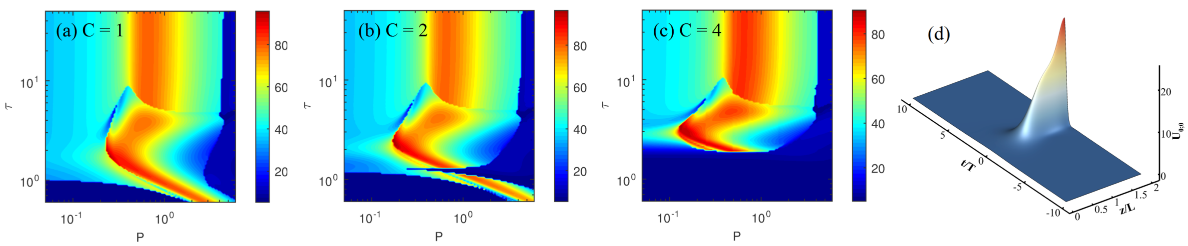

Fig. 2. The dependence of the percentage of total energy E combined in the central core at the first local maximum of the peak power of input pulse on the parameters P and τ of input Gaussian pulses for the hexagonal 19-core MCF with various values of chirp parameter C. Dynamic of the field in the center core for the best combining case ($C = 2,\ P = 1.776,\ \tau = 2.34$) with 96.5% of energy combining.

It is known [3] that a width of a positively chirped pulse may be reduced in anomalous dispersive media. A launching of positively chirped Gaussian pulses significantly improves the pulse compression scheme using MCF (see Fig. 2). The maximum percentage of total energy E coherently combined at the central core equals 96.5% (96% at the central peak of the compressed pulse) for $C = 2$. Although the pulse compression factor equals only 8.05 for this best combining case.

3. Conclusions

In summary, we have demonstrated an effective nonlinear scheme for combining and compressing pulses using a 19-core hexagonal MCF. Initial positive chirping of injected pulses significantly increases the maximum coherently combined energy percentage up to 96.5%.

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